LARGE SCALE COMPOSTING AS A MEANS OF MANAGING WATER HYACINTH

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John Edward Montoya, B.S.

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LARGE SCALE COMPOSTING AS A MEANS OF MANAGING

WATER HYACINTH

Committee Members Approved:

_____

Dr. Tina Marie Cade, Chair

_____

Dr. Mike Abbott

_____

Dr. Paula Williamson

Approved:

_____

J. Michael Willoughby
Dean of Graduate College

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ABSTRACT

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WATER HYACINTH

by

John Edward Montoya

Texas State University-San Marcos, Texas

December 2010

SUPERVISING PROFESSOR: TINA MARIE CADE

Water hyacinth is one of the most invasive aquatic species worldwide. It has been successfully composted in the past, but a large scale system had not been investigated to determine if all plant propagules are destroyed in the process. The intent of this study was to determine if composting is an effective means of managing water hyacinth while producing a quality compost product for the horticultural industry. The first objective of this study was to germinate seeds of water hyacinth by implementing germination tests that have shown success in related studies. It was found in this study that 62% (62/100) of water hyacinth seeds successfully germinated on filter paper media soaked in distilled water and placed in petri dishes held at a constant temperature of 80 degrees Fahrenheit for 14 days. The second objective of this study was to determine the temperatures at

which water hyacinth seeds are rendered non-viable. This study found that water hyacinth seeds were rendered non-viable at temperatures at or above 135 degrees Fahrenheit. The third objective of this study was to develop a large-scale composting system at the Texas State Muller Farm that uses water hyacinth harvested from Spring Lake and nearby areas of the San Marcos River as a feedstock. This study created 11 compost piles derived from 22,000 pounds of water hyacinth, 20,000 pounds of food waste, 25,000 pounds of poultry litter, and 38,000 pounds of wood chips. The fourth objective of this study was to determine if the composting process renders water hyacinth seeds and propagules non-viable. Results of this study indicated that the composting process reached and sustained high enough temperatures to kill and fully decompose seeds and other propagules of water hyacinth. Therefore, water hyacinth can be composted without the potential danger of it spreading. The fifth objective of this study was to determine the quality of the compost produced. This study found that the quality of compost created from water hyacinth was in the acceptable to ideal ranges of given industry quality standards, though there was a learning curve by the student workers in the preparation of the piles using the large equipment. The sixth objective of this study was to determine how and if the removal of water hyacinth impacts water quality. This study did not indicate that the removal of water hyacinth impacted the water quality of the area either negatively or positively.

CHAPTER 1

INTRODUCTION

The water hyacinth, ***Eichhornia crassipes***, is considered to be one of the most invasive plant species worldwide (Gopal 1987). Water hyacinth is a native of the Amazon River, most likely from Brazil (Penfound and Earle 1948). It became a nationwide aquatic weed problem during the last century after its introduction to the United States in 1884 at the Centennial Exposition in New Orleans (Gopal 1987). At the exposition, it was the featured South American horticultural display and attracted great attention (Monsod 1979). From New Orleans, the water hyacinth was transported to Florida by an attendee of the centennial expedition (Monsod 1979). It was shared with fellow gardeners and planted in garden ponds across Florida (Monsod 1979). When a flood hit Florida, the water hyacinth was spread to Texas and soon it was found from Virginia to Northern California (Monsod 1979). Presently, water hyacinth is found in all major rivers worldwide (Gopal 1987).

The problems caused by water hyacinth include obstructing waterways, impeding drainage, destroying wildlife resources, reducing outdoor recreation opportunities, and lowering dissolved oxygen levels resulting in reduced available oxygen for animals and other plants (Gopal 1987). Harvesting and using the plant for animal feed, compost, fertilizer, energy (biofuel), paper and water pollution control at wastewater treatment plants have been explored (Gopal 1987). Herbicides (2,4-D) have been used to kill the

plant, but this is not preferred for use in sensitive habitats such as the San Marcos River (Gopal 1987). Biological and environmentally safe types of solutions are the most appealing because water hyacinth grows in environmentally sensitive areas and important waterway systems (Gopal 1987).

The campus of Texas State University–San Marcos includes Spring Lake, which is fed from springs of the Edwards Aquifer and is the headwaters of the San Marcos River. The ecosystem of Spring Lake is critical habitat for endangered and threatened species including the Fountain Darter (*Etheostoma fonticola*), San Marcos Salamander (*Eurycea nana*), Texas Blind Salamander (*Typhlomolge rathbuni*), San Marcos Gambusia (*Gambusia georgei*), and Texas Wild Rice (*Zizania texana*) (Bartlett and Williamson 1995). These endangered and threatened species are dependent upon stable water quality that is rich in dissolved oxygen. Depleted oxygen levels prevent fish from functioning properly and can be very harmful to endangered and threatened species. Spring Lake and nearby areas of the San Marcos River are becoming inundated by water hyacinth which depletes dissolved oxygen levels and changes the underwater ecosystem. The harvesting of water hyacinth will help maintain the oxygen levels and ecosystems that are necessary for survival of the endangered and threatened species (Gopal 1987).

Composting is a biological process in which microorganisms convert organic materials into a soil-like material called compost (Rynk *et al.* 1992). While composting, microorganisms consume oxygen and release carbon dioxide (Rynk *et al.* 1992). Active composting produces a large amount of heat, and releases water vapors into the air (Rynk *et al.* 1992). The volume of the finished compost is 50% or less of the volume of raw material (Rynk *et al.* 1992). This makes composting an effective means of waste control

(Stoffella and Kahn 2001). Preventing the loss of top soil by directly adding compost to the soil surface also makes compost an effective means of erosion control (Stoffella and Kahn 2001). Compost has also been used in revegetation projects and mine reclamation as a topsoil and soil amendment for disturbed landscapes (Rynk *et al.* 1992). Currently, the highest demand for compost lies in the horticultural industry where it is primarily used in landscaping and in the greenhouse (Stoffella and Kahn 2001). In addition, compost is utilized by horticulturalists in vegetable, fruit, ornamental, nursery, and turf crop production systems (Stoffella and Kahn 2001). Compost has also been found to reduce plant diseases, help with weed control, and increase the accessibility of nutrients by plants (Stoffella and Kahn 2001). In Texas, the potential industry opportunity is very high for compost, as it used by the Texas Department of Transportation (TxDOT) for erosion control on highway right-of-ways and during construction of highways (Pearson 2003).

Problem Statement

The main objective of this study was to determine if large scale composting is an effective means of managing water hyacinth by rendering the seeds and other propagules non-viable while producing a quality compost product for the horticultural industry.

Purpose and Objectives

The purpose of this study was to determine if large scale composting is an effective means of managing water hyacinth by rendering the seeds and other propagules non-viable.

The specific objectives of this study were to:

1) Germinate seeds of water hyacinth by implementing germination tests that have shown success in related studies (Gopal 1987).

2) Determine the temperatures at which water hyacinth seeds are rendered non-viable.

3) Develop a large-scale composting system at the Texas State Muller Farm that uses water hyacinth harvested from Spring Lake and nearby areas of the San Marcos River as a feedstock.

4) Determine if the composting process renders water hyacinth seeds and propagules non-viable.

5) Determine the quality of the compost produced.

6) Determine how and if the removal of water hyacinth impacts water quality.

Hypotheses

The following hypotheses will be tested:

1) Heat created by large-scale compost piles will render water hyacinth seeds non-viable and will decompose other propagules that would asexually reproduce the plant.

2) Water hyacinth will be an effective feedstock for large-scale composting.

3) Large-scale composting will be a safe and effective disposal system for water hyacinth.

4) The compost produced will be of acceptable quality determined by the Seal of Testing Assurance Program (STA).

5) Removal of water hyacinth will positively affect water quality.

Definition of Terms

Composting: Biological degradation of organic matter under aerobic conditions to a relatively stable humus-like material called compost (Rynk *et al.* 1992).

Curing: Final stage of composting in which stabilization of the compost continues, but the rate of decomposition has slowed to a point where turning or forced aeration is no longer necessary. Curing generally occurs at lower, mesophilic temperatures (Rynk *et al.* 1992).

Ecosystem: A level of ecological study that includes all the organisms in a given area as well as the abiotic factors with which they interact; a community and its physical environment (Campbell *et al.* 1999).

Endangered Species: A species that is in danger of extinction throughout all or significant portions of its range (Campbell *et al.* 1999).

Feedstock: The raw materials or ingredients for composting (Rynk *et al*. 1992).

Germination: The process by which a dormant seed begins to sprout and grow into a seedling under the right growing conditions (Campbell *et al.* 1999).

Invasive Species: Species that invade undisturbed or lightly disturbed habitats (Barbour *et al.* 1998).

Mesophiles: Organisms including bacteria, fungi, actinomycetes and invertebrates present in compost at temperatures between 50 and 105 degrees Fahrenheit. These organisms begin the process of composting and recolonize the pile during the curing phase (Rynk *et al.* 1992).

Skid-loader: A vehicle which employs a hydraulically operated bucket to lift materials (Rynk *et al*. 1992).

Spring Lake: An artificial lake created by two small dams at the head waters of the San Marcos River. The San Marcos Springs emerge from the ground in this area and maintain the lake's water level and temperature. The water temperature is a constant 72 degrees Fahrenheit (Nelson 1944).

Thermophiles: Organisms including bacteria, fungi and actinomycetes present in compost at temperatures between 105 and 170 degrees Fahrenheit (Rynk *et al.* 1992).

Threatened Species: Species that are likely to become endangered in the foreseeable future throughout all or significant portions of its range (Campbell *et al.* 1999).

Turning: Mechanical agitation of the composting materials (Rynk *et al.* 1992).

Windrow: A long, relatively narrow, and low compost pile. Windrows have a large exposed surface area which encourages passive aeration and drying (Rynk *et al.* 1992).

Limitations

The limitations of the study include the following:

1) Using a skid-loader to turn the compost piles instead of a windrow turner may have created less uniformity within the windrows.

2) The study was limited to using poultry litter, university cafeteria waste, wood chips, saw dust, and water hyacinth as feedstocks for the compost piles.

3) The study was limited to 11 compost piles at any one time.

4) Any research conducted in a natural environment is subject to extraneous factors that can influence the outcome of the study.

5) The study was limited to water hyacinth taken from the same habitat, Spring Lake, San Marcos, Texas.

6) The oven seed kill tests only included 3 temperatures, 120, 135, and 150 degrees Fahrenheit.

7) Wood chips used as feedstocks may have varied based on the waste material harvested by 1 tree care company.

8) Food waste may have varied based on the cafeteria menu at 2 university cafeterias.

9) The study was limited to a 2 year time span.

Basic Assumptions

1) Water hyacinth harvested from Spring Lake and nearby areas of the San Marcos River was of a consistent quality.

2) Food waste from the university cafeteria was of a consistent quality.

3) Bark chips from the tree care company was of a consistent quality.

4) The compost curing phase was achieved in approximately 4 weeks.

5) Ovens were accurate and maintained a constant temperature.

6) Moisture meter and thermometer and other measurement devices used in the study produced accurate readings.

7) Random samples taken from curing compost captured water hyacinth seeds if they were present after the composting process.

8) Germination and tetrazolium tests led to accurate results.

9) Oven seed tests led to accurate results.

CHAPTER II

REVIEW OF LITERATURE

History of the Water Hyacinth

Water hyacinth is a native of the Amazon River, most likely from Brazil (Penfound and Earle 1948). It became a nationwide aquatic weed problem during the last century after its introduction to the United States in 1884 at the Centennial Exposition in New Orleans, LA (Gopal 1987). At the exposition, it was the featured South American horticultural display and attracted great attention (Monsod 1979). From New Orleans, the water hyacinth was transported to Florida by an attendee of the Centennial Exposition (Monsod 1979). It was shared with fellow gardeners and planted in garden ponds across Florida (Monsod 1979). When a flood hit Florida, water hyacinth spread to Texas, and soon it was located from Virginia to Northern California (Monsod 1979). Presently, water hyacinth is found in all major rivers worldwide (Gopal 1987). Water hyacinth is listed as invasive in 5 states and over 30 countries around the world (GISD 2005). In its native region, water hyacinth is not considered a pest because it is regulated by species that have co-evolved with it such as the weevil (Gopal 1987).

Vegetative Propagation of Water Hyacinth

Water hyacinth primarily reproduces by vegetative means through enlarged stolons that produce offshoots at their ends (Barrett 1980). Favorable conditions for

water hyacinth are warm temperatures (72.5-95 degrees Fahrenheit), high nutrient content, and high humidity (>90%) (Gopal 1987). It has been found that, given favorable conditions, the numbers of water hyacinth plants will double every 12.5 days (Penfound and Earle 1948). In one study, it was estimated that 2 plants would multiply to 1200 in 120 days (Poling and Barr 1965; Gopal 1987). Penfound and Earle (1948) found that in Louisiana, in a normal spring season, 1 water hyacinth plant could grow to over 65,000 plants.

Sexual Reproduction of Water Hyacinth

Observation by researchers of sexual reproduction in water hyacinth populations have been limited (Penfound and Earle 1948; Barrett 1980; Gopal 1987). The first reports of water hyacinth had concluded that sexual reproduction was rare at best (Gopal 1987). In field studies, no mature fruits, seeds, or seedlings were found in Guyana, Uruguay, Brazil, Argentina, or Trinidad (Thomas and Mitchell 1972). There were also studies in California that failed to find any evidence of sexual reproduction (Bock 1966). However, seedlings were reported in Texas and Louisiana, as well as seed production in fruits (Barrett 1980).

Water Hyacinth Flowers, Fruit & Seed Development

The flowers of the water hyacinth have been of great interest to botanists for many years (Penfound and Earle 1948). The flowers are borne on a terminal inflorescence and are an "attractive lavender spike subtended by two bracts and surmounted on an elongated peduncle" (Penfound and Earle 1948, pg. 452). Individual spikes have around 4 to 25 flowers, though numbers as high as 35 have been recorded

(Gopal 1987). After all the flowers on the inflorescence have opened, the inflorescence axis bends downwards and submerges the flowers (Gopal 1987). Fruit development commonly occurs while the inflorescence is submerged in water, though the fruit has also been known to develop outside of water (Gopal 1987). Maximum fruiting occurs at a relative humidity greater than 90% and temperature between 72.5–95 degrees Fahrenheit (Gopal 1987, pg. 103). The fruit and seed production of water hyacinth varies greatly among different populations (Gopal 1987). The number of seeds per fruit varies from a few to over 450 (Gopal 1987). The size of the seeds is relatively small with a maximum size of around 4 millimeters long by 1 millimeter wide (Gopal 1987). Seed maturation generally takes from 16 to 32 days (Gopal 1987).

Pontederiaceae is only 1 of 3 plant families that have floral trimorphism (Gopal 1987). Floral trimorphism is when a species has 3 distinctly different style types. The water hyacinth has short-styled, mid-styled, and long-styled flowers (Gopal 1987). Of the 3 style types, the mid-styled is the form that is most widely spread, but the long-styled form has been found in several countries (Gopal 1987). The short-styled type is located only in the native region (South America) of water hyacinth (Gopal 1987). Pollen of the water hyacinth also exhibits trimorphism (Gopal 1987). Trimorphism has been thought to promote self-incompatibility, but in water hyacinth it is viewed as a "non-functional morphological feature" (Gopal 1987, pg. 104).

It was found that only around 35% of flowers are pollinated under natural conditions with wind being an important pollinating agent (Agharkar and Banerji 1930; Talatala and Soerjani 1975). Four groups of bees have been known to visit water hyacinth flowers in its native region and help with pollination (Barrett 1980). The groups

are Anthophoridae, Megachilidae, Meliponidae, and a species of Halictidae (Barrett 1980; Gopal 1987). However, experiments using bags discovered that self pollination occurs to a high degree (Gopal 1987). It has been found that maximum seed set is achieved if the flower is pollinated in the early morning during sunny conditions (Bruhl and Sengupta 1927).

Water Hyacinth Seed Germination

There are numerous inconsistent reports on the environmental requirements for seed germination (Gopal 1987). The first reported germination of water hyacinth seeds was recorded by Mueller in 1883 (Gopal 1987). In this study, germination occurred only after drying the seeds. Since Mueller's study there have been many conflicting reports on the conditions necessary for germination. In contrast to Mueller's study, it was later found that a drying out period was not required for germination (Penfound and Earle 1948). Another study found that alternating the wetting and drying of the seeds was required for germination (Robertson and Thein 1932). Other studies found that a storage period of 10 weeks for wet stored seeds, and 16 weeks for dry stored seeds was necessary for germination (Hitchcock *et al.* 1949; Ueki and Oki 1979). A similar study by Barton and Hotchkiss found that dry stored seeds required twice the amount of time in order to germinate when compared to wet stored seeds (1951). In contrast, Obeid and Tag el Seed (1976) reported 100% germination in dry or wet stored seeds, as well as fresh seeds.

Problems Caused by Water Hyacinth

Water hyacinth blocks waterways used by boats, impedes drainage canals on farm lands, and destroys wildlife habitat. It was found that water hyacinth in the course of 5

years could render a drainage canal 5 feet deep and 20 feet wide to barely function at all (Penfound and Earle 1948). Water loss is also a problem caused by water hyacinth. In the Chambal area of India, it is estimated that more than 700 million cubic meters of water is lost annually, a volume that could grow 116,800 hectares of wheat (Gopal 1987). Water flow has also been impeded by water hyacinth, since water hyacinth has been known to slow water flow by 40–95% (Bogart 1949; Guscio *et al.* 1965; Gopal 1987). This obstruction may be the source of flooding in some areas as spill ways become overrun with water hyacinth (Gopal, 1987). Water loss from evapotranspiration is over 2-3 times the water lost in open conditions (Penfound and Earle 1948). It was found in Texas that every year, 2.5 billion cubic meters of water is lost from reservoirs and rivers due to water hyacinth, a loss estimated at a value of $83 million dollars (Benton *et al.* 1978). One hectare of water hyacinth is estimated to have an oxygen depleting load equal to that of the sewage created by 80 people (Raynes 1964; Gopal 1987). Depleted oxygen levels prevent fish from functioning properly and can alter ecosystems to be very harmful to endangered and threatened species (Gopal 1987).

Water hyacinth also lowers the pH and temperature of the water, altering critical habitats of adapted and native species (Reddy *et al.* 1983). It has also been reported that water hyacinth increases mosquito populations (Barber and Haynes 1925; Penfound and Earle 1948). Additionally, water hyacinth takes over submerged plant species, an important part of the waterfowl diet (Penfound and Earle 1948). Closed mats of water hyacinth prevent all fish except for top minnows from utilizing the habitat due to oxygen depletion (Penfound and Earle 1948).

Possible Utilization of Water Hyacinth

Water hyacinth has a number of possible utilizations. Some of these include animal feed, compost, paper, energy, and wastewater treatment (Gopal 1987). Other uses include "processing of the plant into badly needed nutrients for humans, like protein, Vitamin A, Vitamin B-2 (Riboflavin), Vitamin E, Vitamin B-12, and Xantophyll" (Monsod 1979, pg. 31). In the Philippines, Indonesia, and Thailand, water hyacinth has been used to make baskets, handbags, hats, ropes, stuffing for upholstery, and even shoe soles (Monsod 1979; Gopal 1987).

Compost from Water Hyacinth

Using water hyacinth as a feedstock for compost has been reported as early as 1925 (Gopal 1987). It was made using earth, cow manure, and wood ash between layers of fresh water hyacinth which was then covered with earth (Gopal 1987). Compost from water hyacinth has also been prepared by using the plants dry and mixing them with wood ash, soil, farmyard manure and vegetable refuse (Gopal 1987).

Studies on crops grown with water hyacinth compost have produced some interesting results. In Sudan, increases in yield have been reported in carrots, red beans, and onions, but the same study also reported a decrease in the yield of okra (Philipp *et al.* 1983; Gopal 1987). The losses in yields were attributed to the relatively high KCl content of water hyacinth compost (Gopal 1987). Utilization for the compost produced has been viewed with caution by such authors as Gopal who raised the question: "what are the effects of heavy metals and toxic substances absorbed by water hyacinth on crops and soil characteristics when used as compost or mulch?" (1987, pg. 313).

Composting Process & Use of Compost in Horticulture

Composting is a biological process in which microorganisms convert organic materials into a soil-like material (Rynk *et al.* 1992). While composting, microorganisms consume oxygen and release carbon dioxide (Rynk *et al.* 1992). Active composting produces a large amount of heat, and releases water vapors into the air (Rynk *et al.* 1992). The primary ingredients of compost are carbon and nitrogen, with a preferred carbon to nitrogen (C:N) ratio of 30:1. The volume of the finished compost is 50% or less of the volume of raw material (Rynk *et al.* 1992). This makes composting an effective means of waste control (Stoffella and Kahn 2001).

The composting process has been found to kill plant pathogens as well as weed seeds (Dougherty 1999). It has been found that "several days of pile temperatures above 130 degrees Fahrenheit are recommended to destroy pathogens and weed seeds" (Dougherty 1999, pg. 47). Pathogens that have been known to be present in compost feedstocks include *E. coli* and *Salmonella* (Stoffella and Kahn 2001). Weed seeds that have been known to exist in compost feedstocks include bindweed (*Convolvulus arvensis*), pigweed (*Amaranthus* spp.), johnsongrass (*Sorghum halepense*) and kochia (*Kochia americana*) (Stoffella and Kahn 2001).

Preventing the loss of top soil by directly adding compost to the soil surface also makes compost an effective means of erosion control (Stoffella and Kahn 2001). Compost has also been used in highway revegetation and mine reclamation as a topsoil and soil amendment for disturbed landscapes (Rynk *et al.* 1992). Currently the highest

demand for compost lies in the horticultural industry where it is used primarily to restore organic matter, help soils retain water and improve drainage (Stoffella and Kahn 2001).

Compost is utilized by horticulturists in vegetable, fruit, ornamental, nursery, and turf crop production systems (Stoffella and Kahn 2001). Landscapers and land developers also use compost as a fertilizer supplement, mulch, and as an alternative in the landscape or field for topsoil (Rynk *et al.* 1992). Compost has also been found to reduce plant diseases, help with weed control, and increase the accessibility of nutrients by plants (Stoffella and Kahn 2001).

Another growing use for compost in the horticulture industry is as a replacement for peat in potting media (Stofella and Kahn 2001). Peat moss is a nonrenewable resource and its extraction has a negative impact on the environment (Stofella and Kahn 2001). This combined with the increasing cost and future reduced availability of peat moss has piqued interest and numerous studies involving compost as an alternative media (Stofella and Kahn 2001).

Compost in Central Texas typically has a cost of approximately 30$ per yard (Greg Frank, personal communication 2010). Horticulturists that could create their own compost could benefit by saving a significant amount of money, especially in Central Texas where compost need is increased due to the low organic content of the local soil (Beck, 1997).

Water Hyacinth and Water Quality

Water hyacinth has been used in numerous studies to control water pollution. Researchers as far back as 1948 had proposed using water hyacinth for the removal of

nutrients from wastewater effluents (Dymond 1948; Gopal 1987, pg. 279). They based their proposition on the fact that water hyacinth grown in wastewater had higher concentrations of nitrogen and phosphorus than water hyacinth grown under normal conditions (Dymond 1948). The removal of nitrogen and phosphorus was studied further in the 1970's and 1980's where it was found that water hyacinth removed 1980 kg N/ha and 322 kg P/ha annually (Boyd 1970). Boyd's (1970) research went on to find that the amount of nitrogen and phosphorus removed per hectare of water hyacinth was equivalent to the sewage created by 500 people.

Another primary reason for using water hyacinth to help manage water pollution is due to the fact that water hyacinth is a heavy metal (iron, manganese, zinc, aluminum, cadmium, lead, mercury, nickel, silver, cobalt, strontium, chromium and copper) accumulator (Gopal 1987). In a study examining the uptake of heavy metals by water hyacinth, it was found that in a pure metal solution containing 3 mg/l of a particular heavy metal, water hyacinth accumulated 1.35 mg cadmium, 1.77 mg mercury, and 1.16 mg of nickel (Widyanto and Susilo 1978; Gopal 1987).

Although there are a number of studies that speak of the removal of pollutants from water by water hyacinth, research has also found that water hyacinth contributes to a decrease in water quality (Gopal 1987). One study found that the oxygen depleting load per hectare of water hyacinth equaled the sewage created by 80 individuals (Raynes 1964; Gopal 1987). Depleted oxygen levels prevent fish from functioning properly and can be very harmful to endangered and threatened species (Gopal 1987).

Importance of Water Hyacinth Removal from Spring Lake

The campus of Texas State University–San Marcos includes Spring Lake, which is fed from springs of the Edwards Aquifer and is the headwaters of the San Marcos River (Nelson, 1944). The ecosystem of Spring Lake is critical habitat for endangered and threatened species including the Fountain Darter (*Etheostoma fonticola*), San Marcos Salamander (*Eurycea nana*), Texas Blind Salamander (*Typhlomolge rathbuni*), San Marcos Gambusia (*Gambusia georgei*), and Texas Wild Rice (*Zizania texana*) (Bartlett and Williamson 1995). These endangered and threatened species are dependent upon stable water quality that is rich in dissolved oxygen (Bartlett and Williamson 1995). Depleted oxygen levels prevent fish from functioning properly and can be very harmful to endangered and threatened species (Gopal 1987). The calm areas and constant temperature of Spring Lake is an ideal environment for water hyacinth to proliferate. Spring Lake is becoming inundated by water hyacinth which depletes dissolved oxygen levels and changes the underwater ecosystem (Gopal 1987). Currently, water hyacinth is harvested out of Spring Lake by hand and deposited on the banks of the river where it is not utilized. Herbicides are commonly used to combat water hyacinth in some water systems, but are not appropriate in sensitive habitats such as Spring Lake and the San Marcos River (Gopal 1987).

Alternative Means of Water Hyacinth Management

Manual and mechanical management of water hyacinth has been practiced with limited success. Developing countries utilize hand tools as the primary means of

removal, but this can be very time consuming and labor intensive (Chokder and Begum 1965). Manual and mechanical control is also limited to suitable weather conditions for removal (Gopal 1987). Innovations have been made in the creation of special equipment (grapplers, modified boats, conveyer belts), but mechanical removal is still viewed as costly and labor intensive (Gopal 1987. The primary benefit of manual and mechanical removal is that it has a minimal impact on the environment compared to other management practices (Gopal 1987).

As mechanical and manual removal of water hyacinth was falling out of favor, chemical management became more attractive. Chemical management was seen as a more effective and less expensive when compared to the drawbacks of manual and mechanical removal (Gopal 1987). The earliest chemicals used to control water hyacinth included poisonous chemicals such as arsenic oxide and formaldehyde which proved to be ineffective to kill the plant (Bose 1923). Currently, the chemical 2,4-D is the most commonly used herbicide on water hyacinth. However, herbicides such as 2,4-D are not suitable for sensitive areas as it has been known to be harmful to fish and can be spread by the wind and unintentionally damage plants and animals in adjacent areas (Sen 1957; Menn 1965).

Biological control of water hyacinth has also received a great deal of attention. Biological control agents primarily include fungi and arthropods, although many other organisms have been researched (Gopal 1987). Mollusks, turtles, carp, and even manatees have been investigated for biological management, but proved to be ineffective (Allen 1938; Allsopp 1960; Ferguson and Butler 1966; Baker *et al.* 1974). Organisms that have shown success in water hyacinth management are weevils (*Neochetina*

eichhorniae, *Neochetina bruchi*) (Moran 2006). Weevils manage the water hyacinth by scaring the leaf tissue as they feed on it which renders the water hyacinth more susceptible to fungus infections that eventually cause mortality (Moran 2006). In a highly sensitive environment such as Spring Lake and the San Marcos River, which is home to several endangered species, biological control may not be desired (Bartlett and Williamson 1995).

The purpose of this study was to determine if large scale composting was an effective means of managing water hyacinth by rendering the seeds and other propagules non-viable while producing a quality compost product for the horticultural industry.

CHAPTER III

METHODOLOGY

The purpose of this study was to determine if large scale composting was an effective means of managing water hyacinth by rendering the seeds and other propagules non-viable.

The specific objectives of this study were to:

1) Germinate seeds of water hyacinth by implementing germination tests that have shown success in related studies (Gopal 1987).

2) Determine the temperatures at which water hyacinth seeds are rendered non-viable.

3) Develop a large-scale composting system at the Texas State Muller Farm that uses water hyacinth harvested from Spring Lake and nearby areas of the San Marcos River as a feedstock.

4) Determine if the composting process renders water hyacinth seeds and propagules non-viable.

5) Determine the quality of the compost produced.

6) Determine how and if the removal of water hyacinth impacts water quality.

Water Hyacinth Seed Collection Techniques

Water hyacinth was collected from various areas of Spring Lake and the San Marcos River during the summer and fall season of 2008. The researcher was responsible for collecting data related to water hyacinth collection. The name and location of each collection site on Spring Lake as well as date and time of collection was logged in field notebooks. Environmental conditions and external equipment used were also recorded. Due to the difficulty of collecting a large amount of seeds in the field, flowering water hyacinth from various locations on Spring Lake and nearby areas were collected and observed at the Agriculture Department's greenhouses at Texas State. Seeds were collected from these samples and stored in small sealable plastic bags in a refrigerator at the Aquarena Center laboratory until needed.

Water Hyacinth Germination Tests

The first objective of this study was to germinate seeds of water hyacinth by implementing germination tests that have shown success in related studies (Gopal 1987). Research has been inconclusive on the optimal conditions for seed germination of water hyacinth (Gopal 1987). Germination testing was employed to determine suitable germination conditions for the seed.

One hundred water hyacinth seeds (50 scarified and 50 unscarified) were placed on filter paper media soaked in distilled water in petri dishes and were observed for 14 days for radical emergence. Research has indicated that water hyacinth seeds will germinate within 14 days (Gopal 1987). The seeds were held in a mini-incubator that was maintained at a constant temperature of 80 degrees Fahrenheit. Previous research

has indicated that 80 degrees Fahrenheit is an optimal temperature for water hyacinth seed germination (Gopal 1987).

Seeds, incubators, and moisture levels were monitored daily during germination tests. The researcher was responsible for collecting data related to water hyacinth seed germination tests. Laboratory data were logged in field notebooks and included the name and location of germination tests, date and time of data collection, environmental conditions, and documentation of external equipment used for each sample treatment. Field notebooks and data collection were the responsibility of the researcher.

Water Hyacinth Oven Seed Kill Tests

The second objective of the research included compiling and analyzing data to determine the temperatures at which water hyacinth seeds were rendered non-viable. The tests included the use of 3 ovens (Model 10AF, Quincy Lab) and were conducted at the Aquarena Center laboratory. In total, 90 compost samples each weighing 226.7 grams and holding 10 viable water hyacinth seeds were tested for 3 days in oven chambers held at temperatures of 120 degrees Fahrenheit, 135 degrees Fahrenheit and 150 degrees Fahrenheit. Oven and sample temperatures were checked daily and the thermometers (Digital Probe Thermometer, Ward's) were traceable to NIST (National Institute of Standards and Technology). Samples were maintained at a 50-70% moisture level by using the accepted practice that the sample was too wet if water can be squeezed out of the sample and too dry if the sample does not feel wet to the touch (Rynk *et al.* 1992).

Of the 90 seed-containing compost samples, 45 of the samples were conducted with scarified water hyacinth seed, and 45 of the samples were conducted with

unscarified water hyacinth seed. Water hyacinth seeds were scarified by soaking the seeds in a 15% vinegar solution for 30 minutes (Blazich and Evans 1999). For both scarified and unscarified seeds, 15 samples were held at 120 degrees Fahrenheit; 15 samples were held at 135 degrees Fahrenheit and 15 samples were held at 150 degrees Fahrenheit which was equivalent to 150 each of scarified and unscarified seeds in total. Once the compost samples were held for the 3 days, seeds were tested using the germination procedures determined from the initial germination testing analysis as well as were tested for viability using tetrazolium tests. The tetrazolium test is a seed viability test that usually takes about 30 minutes to perform. Seed embryos were tested by cutting or piercing the seed coat to expose the embryo. Seeds were then imbibed by soaking them in water, and then the biochemical 2, 3, 5 triphenyl tetrazolium chloride (TTC). While TTC is initially colorless, it is converted to formazan red when living tissue is present (Lakon 1942). Therefore, seed embryos that are respirating or alive will appear stained when soaked in TTC. Dead embryos will not turn red.

The oven seed kill tests used 3 different ovens and 5 replications of the tests listed below with scarified and unscarified seed being tested simultaneously. Three different temperatures were tested, and included:

Oven 1

120 degrees Fahrenheit, 3 compost samples with 10 scarified seed, 3 compost samples with 10 unscarified seed

Oven 2

135 degrees Fahrenheit, 3 compost samples with 10 scarified seed, 3 compost samples with 10 unscarified seed

Oven 3

150 degrees Fahrenheit, 3 compost samples with 10 scarified seed, 3 compost samples with 10 unscarified seed

The researcher was responsible for collecting data related to water hyacinth oven seed kill tests. Name and location of the seed kill tests, sources of sample compost and seeds, date and time of data collection, and environmental conditions were logged in laboratory notebooks. Documentation of external equipment used for sample treatment (tools and instruments used to turn samples; thermometers for double-checking temperatures, spray bottles, etc.), was also recorded. Laboratory notebooks were the responsibility of the researcher.

Compost Pile Construction Monitoring

The third objective of this study was to develop a large-scale composting system at the Texas State Muller Farm that used water hyacinth harvested from Spring Lake and other areas of the San Marcos River as a feedstock. The compost recipe was developed by a composting specialist at the Texas Commission on Environmental Quality (Bill Carter, personal communication 2008). The compost piles included feedstocks at the following percentages: food waste from the cafeterias (10%), poultry litter (15%), water hyacinth plants (25%) and wood chips (50%). Piles were turned every 5 days (when environmental conditions allowed) to ensure that formerly outer exposed surfaces were buried within the pile each time the pile was turned (Rynk *et al.* 1992). Turning was done with a skid-loader (268B, CAT) by the researcher.

Description of Feedstocks:

Texas State Cafeteria Food Waste: For this research study, the compost operation used Commons and Harris cafeteria food waste as a nitrogen and moisture source within the piles. Commons cafeteria food waste is processed through a grinder which makes all of the food of an even "cole slaw" consistency. Harris cafeteria food waste was not processed in this manner and instead included whole food parts. The food waste material was collected in 55 gallon bins with liners and was picked up in the late afternoons daily. This feedstock was utilized because the university reportedly disposes of over 300 tons of food waste a year, with substantial cost from trash hauling fees and allows for a consistent readily available nitrogen-rich waste material from the campus environment.

Poultry Litter: Poultry litter was obtained from Tyson Foods in Seguin, TX. Litter consisted of soiled bedding, feathers, chicken feet, and occasionally whole chicken carcasses. By utilizing poultry litter as feedstock with water hyacinth, it was anticipated that temperatures would reach levels that were likely to render water hyacinth seeds non-viable (Rynk *et al.* 1992). Poultry litter was used as a primary nitrogen source. It was collected by dropping off an empty dump trailer on Mondays at the Tyson Foods facility and picking up the dump trailer on the following Friday.

Water Hyacinth: For the study piles, water hyacinth was collected from various areas of Spring Lake and nearby areas of the San Marcos River during the months of August through December, 2009. Water hyacinth was collected in 44 gallon buckets by raking it from Spring Lake and nearby areas of the San Marcos River by hand while using waders. Water hyacinth was another nitrogen source for the piles, but was also immediately added to the composting system in order to maximize the potential moisture of the material.

Wood Chip Waste: Tree and shrub branches that were pruned by the Bartlett Tree Company were used as the primary carbon source for the composting project. Therefore, species of tree waste varied. Sizes of wood chips were relatively consistent as they were single-grinded by the same grinder at Bartlett Tree Company. Wood chips were collected at Bartlett Tree Company using a dump trailer and a skid loader and picked up from their facility on an as-needed basis.

Rows of feedstock blends were laid out in separate areas and monitored for heat, moisture and maturity. Piles were built to be 5 to 6 feet tall (Rynk *et al.* 1992). The widths of the piles were built to be 10-12 feet (Rynk *et al.* 1992). This height and width allowed the piles to be insulated and generate enough heat to kill pathogens (including the weed seeds of interest), but did not allow too much heat to be generated in the piles which can result in spontaneous combustion (Rynk *et al.* 1992).

Moisture levels were measured with a 60" meter with a precision level of +/- 10 % (Compost Moisture Meter, Reotemp Instrument Corporation). A moisture level of 50-60% is ideal for compost production (Rynk *et al.* 1992). Acidity and alkalinity (pH) was measured with a "Soil pH" sensor (Soil pH direct reading tester, Kelway) with a precision level of +/- 5 %. Acidity and alkalinity levels for compost can vary based on feedstocks. The ideal pH is between 6.8-7.3, but acceptable ranges include a pH from 5.0-8.5 (Rynk *et al.* 1992). Temperatures of the piles were monitored with a windrow thermometer at 6 randomly chosen areas with a precision level of +/- 1 % (Windrow Compost Thermometer, Reotemp Instrument Corporation). Temperatures above 130 degrees Fahrenheit were desired for weed seed kill (Rynk *et al.* 1992). Oxygen levels of piles were controlled through scheduled turning of the piles and measured with a oxygen-

temperature monitor (MF420-0-M, MF420-5T-100, J. Dittrich) regularly. The precision level of this instrument was +/- 2 %.

Once feedstocks were decomposed, piles were moved to another designated area for curing to occur. Compost was moved to the curing area weekly, or as needed. The curing process takes approximately 4 weeks, and is signaled to be ready for curing when the compost pile temperature decreases steadily and reaches mesophilic temperatures (<104F) (Rynk *et al.* 1992). The curing period provides a continued decomposition of large particles, organic acids, and resistant compounds and reduces the probability of immature compost being used (Rynk *et al.* 1992). One of the dangers of using immature compost is that the compost continues to utilize oxygen, which decreases the accessibility of oxygen to the roots of plants (Rynk *et al.* 1992). Two long rows adjacent to the compost production area were used as curing areas. One end of each row had compost that was more mature and the pile progressed to compost that was less mature in the curing process. Alleyways between piles were 25-30 feet.

The researcher was responsible for collecting data related to compost pile construction and monitoring. Name and location of the compost pile, date and time of data collection, type and quantity of feedstock ingredients, source of feedstock ingredients, and age of the pile was logged in field notebooks. Source of feedstock ingredients, treatment of piles, average temperature of pile, condition of the pile, environmental conditions, and external equipment was also recorded.

Compost Sampling for Final Water Hyacinth Seed Germination Tests

The fourth objective of this study was to determine if the composting process renders water hyacinth seeds and propagules non-viable. To observe whether water hyacinth seed survived the composting process, 100 1-gallon sized pots of compost were collected. Sampling began as soon as compost batches were determined to be in a cured state. A cured state was calculated by taking the temperature of the compost as it reduced in heat until eventually it reached lower mesophilic temperatures (<104 degrees Fahrenheit). Individual gallon-sized samples were taken from finished cured piles of compost and at varying depths from curing piles. When samples were drawn, they were labeled with the time, approximate depths and site from which they were gathered. Each gallon-sized compost sample was drawn by collecting at least 5 subsamples from each cured compost pile. These 5 subsamples were then combined to create a composite sample.

Compost samples were taken to the Ladybird Johnson Wildflower Center seed lab in Austin, Texas. Each sample was screened down to particles less than 2mm in size, which would capture any potential water hyacinth seeds while preventing any larger particles from passing through. Each sample was then visually analyzed per Lady Bird Johnson Wildflower Center's seed identifying procedures to determine if water hyacinth seeds were present in each sample (Minnette Marr, personal communication 2010).

Compost Quality Analysis

The fifth objective of this study was to determine the quality of the compost produced. Each of the 11 compost piles were sampled again after all piles had cured.

Samples were taken by collecting approximately 1 pint of material from near the surface of each pile, another pint of material midway to the core of the pile, and another pint of material from near the core of the pile (TMECC 2002). Each of the 3 pints were then placed in a clean 5-gallon plastic bucket and thoroughly mixed. A composite sample of 1 to 2 quarts was then collected from the mixed material (TMECC 2002). This sampling technique was designated as reliable and valid in compost quality testing standards (TMECC 2002).

Pennsylvania State Agricultural Analytical Services Laboratory (University Park, Pennsylvania) utilizes testing procedures from the U.S. Compost Council's Test Methods for the Examination of Composting and Compost (TMECC 2002). The analysis conducted in this study employed the tests for the U.S. Compost Council Seal of Testing Approval (STA) program which provided the analyses required for producers involved with the Compost Council's STA program. This test was the most comprehensive compost test that the Pennsylvania State Agricultural Analytical Services Laboratory performed. The test analyzed percent solids, organic matter, pH, soluble salts, total nitrogen, total carbon, carbon:nitrogen ratio, ammonium-nitrogen, phosphorus, potassium, calcium, magnesium, arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, zinc, respirometry test, bioassay, and particle size (< 9.5 mm) within each compost sample.

Water Hyacinth Removal and its Impact on Water Quality

The last objective of this study was to determine how and if the removal of water hyacinth impacts water quality. Water quality data (electrical conductivity, dissolved

oxygen) were obtained from the River Systems Institute's Stream Team for areas for months before (August 2008-December 2008) and for months after water hyacinth collection (February 2010-March 2010). The Texas Stream Team is a group of volunteers that are trained to gather information about the natural resources of Texas (RSI 2010). Data were limited to the Rivers Systems Institute's Texas Stream Team data collection points, which are generally taken each month. However, there were months during the study period dates of interest that no data were collected. Therefore, the dates of February 2010 – March 2010 were used due to the fact that data for the dates of interest immediately following water hyacinth collection were missing. Frequencies and paired t-tests compared variables from water quality samples taken prior to water hyacinth collection versus those collected after water hyacinth collection dates. Data were then analyzed to determine the impact on water quality by water hyacinth.

CHAPTER IV

RESULTS

The main objective of this study was to determine if large scale composting is an effective means of managing water hyacinth by rendering the seeds and other propagules non-viable while producing a quality compost product for the horticultural industry.

The specific objectives of this study were to:

1) Germinate seeds of water hyacinth by implementing germination tests that have shown success in related studies (Gopal 1987).

2) Determine the temperatures at which water hyacinth seeds are rendered non-viable.

3) Develop a large-scale composting system at the Texas State Muller Farm that uses water hyacinth harvested from Spring Lake and nearby areas of the San Marcos River as a feedstock.

4) Determine if the composting process renders water hyacinth seeds and propagules non-viable.

5) Determine the quality of the compost produced.

6) Determine how and if the removal of water hyacinth impacts water quality.

Findings Related to Objective One

The first objective of this study was to germinate seeds of water hyacinth by implementing germination tests that have shown success in related studies (Gopal 1987).

Research has been inconclusive on the optimal conditions for seed germination of water hyacinth (Gopal 1987). Germination testing was employed to determine suitable germination conditions for the seed for later viability tests.

Water hyacinth seed was collected from water hyacinth plants harvested from various areas of Spring Lake and nearby areas of the San Marcos River during the summer and fall season of 2008. Due to the difficulty of collecting a large amount of seeds in the field, flowering water hyacinth from various locations were collected and observed for fruiting to occur at the Agriculture Department's greenhouses at Texas State. Seeds collected from these samples were stored in a refrigerator at the Aquarena Center laboratory until germination tests were implemented.

One hundred water hyacinth seeds (50 scarified and 50 unscarified) were placed on filter paper media soaked in distilled water in petri dishes and were observed for 14 days for radical emergence. Past research has indicated that water hyacinth seeds germinated within 14 days (Gopal 1987). The seeds in this research study were held in a mini-incubator that was maintained at a constant temperature of 80 degrees Fahrenheit. Previous research indicated that 80 degrees Fahrenheit was an optimal temperature for water hyacinth seed germination (Gopal 1987). Of the 100 seeds tested, 62 successfully germinated, 34 unscarified and 28 scarified (Figure 1). The germination percentage achieved in these tests was consistent with other germination tests that have shown success in previous research (Gopal 1987).

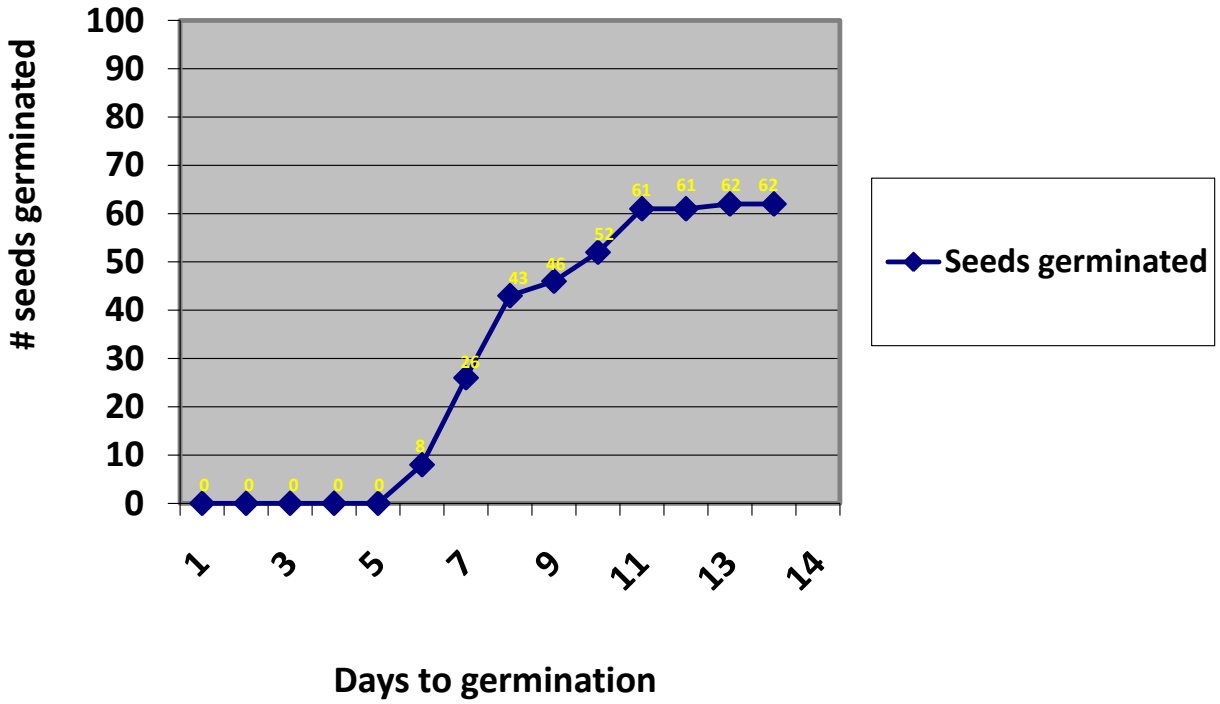

Figure 1: Germination test results illustrating the number of seeds of water hyacinth, *Eichhornia crassipes*, germinated after 14 days using a filter paper media and soaked in distilled water in petri dishes held in an artificial incubator environment in the study of the use of composting as a means to manage the invasive species water hyacinth.

Findings Related to Objective Two

The second objective of this study was to determine the temperatures at which water hyacinth seeds were rendered non-viable. As a waste-management system within agriculture, composting is known to kill weed seeds if temperatures are high enough and maintained for long enough periods of time (Rynk *et al.* 1992). For germination to be inhibited on weed seeds of bindweed (*Convolvulus arvensis*), pigweed (*Amaranthus* spp.), johnsongrass (*Sorghum halepense*) and kochia (*Kochia americana*), temperatures

of 120 to 180 degrees Fahrenheit for three to seven days on average must be obtained (Rynk *et al.* 1992). However, in this study, the temperatures needed to kill seeds of water hyacinth were not yet known. Therefore, seed kill experiments were conducted using small ovens to hold compost and water hyacinth seed samples at varying temperatures to discern at what temperatures the embryos were killed.

The tests included the use of 3 ovens (Model 10AF, Quincy Lab) and were conducted at the Aquarena Center laboratory. Water hyacinth seed was collected from various areas of Spring Lake and nearby areas of the San Marcos River during the summer and fall seasons of 2008. Due to the difficulty of collecting a large amount of seeds in the field, flowering water hyacinth from various locations were collected and observed for fruiting to occur at the Agriculture Department's greenhouses at Texas State. Seeds collected from these samples were stored in a refrigerator at the Aquarena Center laboratory. In total, 90 compost samples weighing 226.7 grams each and individually holding 10 water hyacinth seeds were tested for 3 days in oven chambers held at temperatures of 120 degrees Fahrenheit, 135 degrees Fahrenheit and 150 degrees Fahrenheit. These temperatures replicated the environment and temperatures that could be achieved in an active compost pile. Oven and sample temperatures were checked daily with thermometers (Digital Probe Thermometer, Ward's) traceable to NIST (National Institute of Standards and Technology). Samples were monitored daily and maintained at a 50-70% moisture level, which is the typical moisture level of an active compost pile (Rynk *et al.* 1992). Moisture levels were maintained by using the rule of thumb that the sample was too wet if water can be squeezed out of the sample and too dry if the sample does not feel wet to the touch (Rynk *et al.* 1992).

Previous research was inconclusive regarding the need to scarify water hyacinth seeds for successful germination; as a result, both scarified and unscarified seeds were used for the oven seed kill tests (Gopal 1987). Of the 90 seed-containing compost samples, 45 of the samples were conducted with scarified water hyacinth seed, and 45 of the samples were conducted with unscarified water hyacinth seed. Water hyacinth seeds were scarified by soaking the seeds in a 15% vinegar solution for 30 minutes (Blazich and Evans 1999). For both scarified and unscarified seeds, 15 samples were held at 120 degrees Fahrenheit; 15 samples were held at 135 degrees Fahrenheit and 15 samples were held at 150 degrees Fahrenheit. Fifteen samples and 150 scarified and unscarified seeds were treated at each temperature (Table 1). Three samples at each temperature were treated at one time, and each sample of compost was turned at least 3 times during the 15 day treatment period in order to mimic conditions in an actual large scale composting system (Rynk *et al.* 1992). Once the seeds were held for 15 days, they were tested using the germination procedures determined from the initial germination testing analysis in which seeds were germinated in petri dishes held at 80 degrees Fahrenheit.

Seeds were also tested for viability using tetrazolium tests. The tetrazolium test is a seed viability test that usually takes about 30 minutes to perform. Seed embryos are tested by cutting or piercing the seed coat to expose the embryo. Seeds are then imbibed by soaking them in water, and then biochemical 2, 3, 5 triphenyl tetrazolium chloride (TTC). While TTC is initially colorless, it is converted to formazan red when living tissue is present (Lakon 1942). Therefore, seed embryos that are respirating or alive will appear stained when soaked in TTC. Dead embryos will not turn red. In the first germination tests, no seeds germinated from the sample in the compost samples held at

120, 135 and 150 degrees Fahrenheit. However, using tetrazolium tests, 2 water hyacinth seeds were found to be viable of the unscarified seeds maintained in the compost sample held at 120 degrees Fahrenheit (Table 1).

The results of the second set of germination tests saw no germination of any of the seeds maintained in the compost samples held at 120, 135, and 150 degrees Fahrenheit (Table 1). Tetrazolium tests found none of the seeds in the second set of germination tests to be viable. Therefore, researchers concluded that compost piles must be maintained at temperatures of at least 135 degrees Fahrenheit in order to ensure that water hyacinth seed will rendered non-viable. These results were similar to those of previous studies with other plant species (Rynk *et al.* 1992).

TABLE 1.

Germination[z] and tetrazolium[y] test results conducted with scarified[x] and unscarified *Eichhornia crassipes*, water hyacinth seed in the study of the use of composting as a means to manage the invasive species water hyacinth.

Group	Seeds Germinated[z]	Germination (%)	Embryos Stained in Tetrazolium Test[y]	Stained (%)
Unscarified seed				
120° Fahrenheit	0/300	0	2/300	0.7
135° Fahrenheit	0/300	0	0/300	0
150° Fahrenheit	0/300	0	0/300	0
Total	0/900	0	2/900	0.1
Scarified seed[x]				
120° Fahrenheit	0/300	0	0/300	0

Table 1 Cont.

135° Fahrenheit	0/300	0	0/300	0
150° Fahrenheit	0/300	0	0/300	0
Total	0/900	0	0/900	0

[z]Germination tests were conducted using water hyacinth seeds placed on filter paper media soaked in distilled water in petri dishes and were observed for 14 days for the radical emergence.

[y]The tetrazolium test is a seed viability test that usually takes about 30 minutes to perform. Seed embryos are tested by cutting or piercing the seed coat to expose the embryo. Seeds are then imbibed by soaking them in water, and then biochemical 2, 3, 5 triphenyl tetrazolium chloride (TTC). While TTC is initially colorless, it is converted to formazan red when living tissue is present. Therefore, seed embryos that are respirating or alive will appear stained when soaked in TTC. Dead embryos will not turn red.

[x]Seeds were scarified by soaking in a vinegar 15% solution for 30 minutes.

Findings Related to Objective Three

The third objective of this study was to develop a large-scale composting system at the Texas State Muller Farm that used water hyacinth harvested from Spring Lake and other areas of the San Marcos River as a feedstock. Texas State Muller farm was previously utilized as an alternate grazing source for the livestock kept at Texas State Freeman Ranch. Muller Farm is approximately 125 acres and 5 acres were allocated for the compost site. Of the 5 acres allocated for the compost site, 2.285 acres were transformed into a catchment pond that could withstand a 25 year/24 hour rain event. The remaining 2.715 acres were cleared and graded so that any water run-off from the compost piles would be captured by the pond. Fences and gates were also installed to keep out any livestock and to contain the feedstocks used for composting.

Eleven identical piles in total were constructed for the study. The compost piles included feedstocks at the following percentages: food waste from the cafeterias (10%), poultry litter (15%), water hyacinth plants (25%), and wood chips (50%).

Description of Feedstocks:

Texas State Cafeteria Food Waste: The compost operation used Commons and Harris cafeteria food waste as a nitrogen and moisture source within the piles. A total of 20,000 pounds of food waste was collected in this study. Food waste totals were estimated by weighing 44 gallon bins full of food waste and creating an average.

Poultry Litter: Poultry litter was obtained from Tyson Foods in Seguin, TX. Litter consisted of soiled bedding, feathers, chicken feet, and an occasional chicken carcass. A total of 25,000 pounds of poultry litter was collected in this study. Poultry litter was weighed on a scale at Tyson Foods.

Water Hyacinth: Water hyacinth was collected from various areas of Spring Lake and nearby areas of the San Marcos River. A total of 22,000 pounds of water hyacinth was collected in this study. Water hyacinth totals were estimated by weighing 44 gallon bins full water hyacinth and creating an average.

Wood Chip Waste: Tree and shrub branches that were pruned by the Bartlett Tree Company were used as the carbon source for the composting project. Wood chips were collected at Bartlett Tree Company using a dump trailer and a skid loader. A total of 38,000 pounds of wood chips were collected in this study. Wood chips totals were estimated by using a 500lb/yard estimate (Rynk *et al.* 1992).

Compost piles were built by mixing the feedstocks and constructing the piles with a CAT 268B Skid Loader. Each pile took approximately 45 minutes to an hour to be constructed once all feedstocks were gathered. Oxygen levels, moisture, temperature and pH were monitored daily. Moisture levels were measured with a 60" meter with a

precision level of +/- 10 % (Compost Moisture Meter, Reotemp Instrument Corporation). A moisture level of 50-60% was maintained daily for optimal compost production. Acidity and alkalinity (pH) was measured with a "On the go pH" sensor (On the go pH sensor, Veris Technologies) with a precision level of +/- 5 %. Acidity and alkalinity levels were measured because they can vary based on feedstocks. Carbon to nitrogen ratios were measured by observing the feedstock blends and using a compost mix calculation (TMECC 2002). Temperatures of the piles were monitored with a windrow thermometer with a precision level of + 1 % (Windrow Compost Thermometer, Reotemp Instrument Corporation). Oxygen levels of piles were monitored through scheduled turning of the piles and measured with the oxygen-temperature monitor (MF420-0-M, MF420-5T-100, J. Dittrich) regularly. The precision level of this instrument is +/- 2 %. Compost piles were turned every 5 days on average for approximately a 30 day period to allow the piles to fully decompose before entering the curing phase.

Findings Related to Objective Four

The fourth objective of this study was to determine if the composting process renders water hyacinth seeds and propagules non-viable. To carry out this objective, compost was collected, screened and inspected for seeds.

One hundred 1-gallon samples were taken in total and then hand-screened to ¼ inch. Each gallon-sized compost sample was drawn by collecting at least 5 subsamples at various depths that were then combined to create a composite sample. The screened material was then taken to Lady Bird Johnson Wildflower Center Seed Lab (Austin, Texas) and further screened, using sieves, to 2mm. The material was then visually examined to see if water hyacinth seeds were present. After visual examination, water

hyacinth seeds were not found to be present in the material. Therefore, no further germination or tetrazolium tests were necessary. Results of this study indicated that the composting process killed and fully decomposed seeds and other propagules of water hyacinth.

Findings Related to Objective Five

The fifth objective of this study was to determine the quality of the compost produced. Each of the 11 compost piles was sampled and samples were sent to the Pennsylvania State Agricultural Analytical Services Laboratory (University Park, Pennsylvania) for testing. Pennsylvania State Agricultural Analytical Services Laboratory was chosen because it was one of the closest composting testing laboratories that performed all of the tests needed and had the capacity to process the 11 samples in a timely manner. Samples were taken by collecting approximately 1 pint of material from near the surface of each pile, another pint of material midway to the core of the pile, and another pint of material from near the core of the pile (TMECC 2002). This process was repeated at each of the sampling locations and was then placed in a clean 5-gallon plastic bucket and thoroughly mixed. A composite sample of 1 to 2 quarts was then collected from the mixed material (TMECC 2002).

Pennsylvania State Agricultural Analytical Services Laboratory utilizes testing procedures from the U.S. Compost Council's Test Methods for the Examination of Composting and Compost (TMECC 2002). The analysis conducted in this study employed the tests for the U.S. Compost Council Seal of Testing Approval (STA) program which provides the analyses required for producers involved with the Compost Council's STA program. This test is the most comprehensive compost test that the

Pennsylvania State Agricultural Analytical Services Laboratory performs. The test analyzes percent solids, organic matter, pH, soluble salts, total nitrogen, total carbon, carbon:nitrogen ratio, ammonium-nitrogen, phosphorus, potassium, calcium, magnesium, arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, zinc, respirometry test, bioassay, and particle size (< 9.5 mm).

The pH of the finished compost was measured by making a slurry of compost and deionized water and then blended to a ratio of 1:5. The sample was then shaken for 20 minutes at room temperature to allow the salts to dissolve in the deionized water. The pH was then measured with an electrometric pH meter (TMECC 2002). The pH of the finished compost ranged from 7.9 to 8.4, which is slightly alkaline, but still within the typical pH range of compost (5.0-8.5).

The soluble salts were measured by taking the electrical conductivity in a 1:5 (compost:water, weight ratio) slurry and was measured in units of millimhos/cm. The soluble salt content of the finished compost in this study ranged from 0.33 to 2.28 mmhos/cm. Compost soluble salt levels typically range from 1 to 10 mmhos/cm. Four samples were below the typical soluble salt level (Table 2). These samples were from the first 4 piles constructed and likely fell below the typical range due to inexperienced equipment operators at the beginning of the study which resulted in clay and other materials being inadvertently mixed in with the compost.

The % solids and % moisture were measured by weighing a sample and then drying it at 70 (+/- 5) degrees Celsius and then re-weighed. The remaining dry solids fraction represented the total solids, and the evaporated fraction represented the % moisture (TMECC 2002). The % solids of the finished compost in this study ranged

from 51.3% to 73.3%. An ideal % solid for finished compost is 50-60%. A total of 6 piles were above the ideal % solid range (Table 2). These piles were the first 6 constructed and likely fell out of the ideal range due to inexperienced equipment operators at the beginning of the study which resulted in clay and other materials being inadvertently mixed in with the compost.

The % moisture of the finished compost in this study ranged from 26.7% to 48.7%. An ideal moisture level of finished compost is 40-50% moisture. A total of 6 piles were below the ideal moisture level (Table 2). These piles were the first 6 constructed and likely fell out of the ideal range due to the older age of the piles which would have allowed for the piles to be somewhat drier.

The % organic matter of the finished compost was measured by using the Loss-On-Ignition Organic Matter Method; which is a direct determination method that indicates organic matter content by quantifying the amount of solid material combusted relative to the original oven dried sample (TMECC 2002). The % organic matter of the finished compost in this study ranged from 13.4% to 43.9% (dry weight basis). Finished composts typically have an organic matter content of 30-70%. A total of 6 piles were below the typical range of organic matter content (Table 2). These piles were the first 6 constructed and likely fell out of the typical range due to inexperienced equipment operators at the beginning of the study which resulted in clay and other materials being inadvertently mixed in with the compost.

The nitrogen content of the finished compost was determined by using the methodologies specified in the Test Methods for the Examination of Composting and Compost (TMECC 2002), specifically the Total Kjeldahl Nitrogen Semi-Micro Kjeldahl

technique (TMECC 2002). The total nitrogen content of the finished compost in this study ranged from 0.6% to 1.8% (dry weight basis). Typical total nitrogen levels of finished compost range from 0.5% to 2.5%.

The total carbon content of the finished compost in this study was measured by the Combustion with CO_2 Detection method. This method uses a carbon analyzer (Leco CR-12) to determine total organic carbon in compost. The analyzer operates on the principle of total combustion of a sample in an oxygen-rich atmosphere of a 2500 degree Fahrenheit resistance furnace (TMECC 2002). The CO_2 produced by the combustion is swept into an oxygen stream through anhydrone tubes to scrub H_2O vapor from the stream (TMECC 2002). The CO_2 stream is then fed into the infrared detector and the amount of CO_2 produced is measured. The total carbon content of the finished compost in this study ranged from 10.4% to 24.5% (dry weight basis). Typical carbon content of compost has up to 54% total carbon.

The carbon to nitrogen ratio of the finished compost in this study ranged from 13.8 to 18.9 (dry weight basis). A low C:N ratio (< 20) will mineralize or break-down organic N to inorganic (plant-available) N.

TABLE 2.

Finished compost test results from certified quality testing laboratory[z] in the study of the use of composting as a means to manage the invasive species water hyacinth.

Sample 1 Analyte	Results (As is basis)	Results (Dry weight basis)	Normal Range
pH[y]	8.1	n/a	5.0 – 8.5
Soluble Salts[x] (1:5 w:w)	0.38 mmhos/cm	n/a	1 – 10 mmhos/cm
Solids[w]	73.3%	n/a	50 – 60%

Table 2 Cont.

Moisture[v]	26.7%	n/a	40 – 50%
Organic Matter[u]	9.8%	13.4%	30 – 70% (Dry weight)
Total Nitrogen[t]	0.5%	0.7%	0.5 – 2.5% (Dry weight)
Organic Nitrogen[s]	0.5%	0.7%	n/a
Ammonium N[r]	3.6 mg/kg	5.0 mg/kg	n/a
Carbon[q]	8.3%	11.3%	< 54%
Carbon:Nitrogen Ratio	16.40	16.4	< 20 (Dry weight)
Phosphorus[p]	0.27%	0.37%	n/a
Potassium[o]	0.51%	0.69%	n/a
Sample 2 Analyte	Results (As is basis)	Results (Dry weight basis)	Normal Range
pH[y]	8.4	n/a	5.0 – 8.5
Soluble Salts[x] (1:5 w:w)	0.33 mmhos/cm	n/a	1 – 10 mmhos/cm
Solids[w]	69.6%	n/a	50 – 60%
Moisture[v]	30.4%	n/a	40 – 50%
Organic Matter[u]	10.3%	14.7%	30 – 70% (Dry weight)

Table 2 Cont.

Total Nitrogen[t]	0.4%	0.6%	0.5 – 2.5% (Dry weight)
Organic Nitrogen[s]	0.4%	0.6%	n/a
Ammonium N[r]	3.4 mg/kg	4.9 mg/kg	n/a
Carbon[q]	7.2%	10.4%	< 54%
Carbon:Nitrogen Ratio	17.60	17.60	< 20 (Dry weight)
Phosphorus[p]	0.23%	0.33%	n/a
Potassium[o]	0.44%	0.64%	n/a
Sample 3 Analyte	Results (As is basis)	Results (Dry weight basis)	Normal Range
pH[y]	8.3	n/a	5.0 – 8.5
Soluble Salts[x] (1:5 w:w)	0.45 mmhos/cm	n/a	1 – 10 mmhos/cm
Solids[w]	65.1%	n/a	50 – 60%
Moisture[v]	34.9%	n/a	40 – 50%
Organic Matter[u]	9.4%	14.4%	30 – 70% (Dry weight)
Total Nitrogen[t]	0.4%	0.6%	0.5 – 2.5% (Dry weight)
Organic Nitrogen[s]	0.4%	0.6%	n/a

Table 2 Cont.

Ammonium N[r]	3.2 mg/kg	4.9 mg/kg	n/a
Carbon[q]	7.1%	10.9%	< 54%
Carbon:Nitrogen Ratio	18.90	18.90	< 20 (Dry weight)
Phosphorus[p]	0.25%	0.38%	n/a
Potassium[o]	0.43%	0.66%	n/a
Sample 4 Analyte	Results (As is basis)	Results (Dry weight basis)	Normal Range
pH[y]	8.1	n/a	5.0 – 8.5
Soluble Salts[x] (1:5 w:w)	1.06 mmhos/cm	n/a	1 – 10 mmhos/cm
Solids[w]	67.5%	n/a	50 – 60%
Moisture[v]	32.5%	n/a	40 – 50%
Organic Matter[u]	13.7%	20.3%	30 – 70% (Dry weight)
Total Nitrogen[t]	0.7%	1.0%	0.5 – 2.5% (Dry weight)
Organic Nitrogen[s]	0.7%	1.0%	n/a
Ammonium N[r]	3.3 mg/kg	4.9 mg/kg	n/a
Carbon[q]	9.3%	13.8%	< 54%
Carbon:Nitrogen Ratio	13.80	13.80	< 20 (Dry weight)

Table 2 Cont.

Phosphorus[p]	0.43%	0.63%	n/a
Potassium[o]	0.61%	0.90%	n/a
Sample 5 Analyte	Results (As is basis)	Results (Dry weight basis)	Normal Range
pH[y]	8.1	n/a	5.0 – 8.5
Soluble Salts[x] (1:5 w:w)	0.97 mmhos/cm	n/a	1 – 10 mmhos/cm
Solids[w]	61.6%	n/a	50 – 60%
Moisture[v]	38.4%	n/a	40 – 50%
Organic Matter[u]	15.6%	25.3%	30 – 70% (Dry weight)
Total Nitrogen[t]	0.6%	1.0%	0.5 – 2.5% (Dry weight)
Organic Nitrogen[s]	0.6%	1.0%	n/a
Ammonium N[r]	3.0 mg/kg	4.9 mg/kg	n/a
Carbon[q]	9.5%	15.4%	< 54%
Carbon:Nitrogen Ratio	15.10	15.10	< 20 (Dry weight)
Phosphorus[p]	0.54%	0.87%	n/a
Potassium[o]	0.56%	0.91%	n/a
Sample 6 Analyte	Results (As is basis)	Results (Dry weight basis)	Normal Range

Table 2 Cont.

pH[y]	8.0	n/a	5.0 – 8.5
Soluble Salts[x] (1:5 w:w)	1.42 mmhos/cm	n/a	1 – 10 mmhos/cm
Solids[w]	68.9%	n/a	50 – 60%
Moisture[v]	31.1%	n/a	40 – 50%
Organic Matter[u]	18.2%	26.4%	30 – 70% (Dry weight)
Total Nitrogen[t]	0.8%	1.2%	0.5 – 2.5% (Dry weight)
Organic Nitrogen[s]	0.8%	1.2%	n/a
Ammonium N[r]	3.6 mg/kg	5.2 mg/kg	n/a
Carbon[q]	11.7%	16.9%	< 54%
Carbon:Nitrogen Ratio	13.90	13.90	< 20 (Dry weight)
Phosphorus[p]	0.61%	0.88%	n/a
Potassium[o]	0.67%	0.97%	n/a
Sample 7 Analyte	Results (As is basis)	Results (Dry weight basis)	Normal Range
pH[y]	7.9	n/a	5.0 – 8.5
Soluble Salts[x] (1:5 w:w)	1.91 mmhos/cm	n/a	1 – 10 mmhos/cm
Solids[w]	56.4%	n/a	50 – 60%

Table 2 Cont.

Moisture[v]	43.6%	n/a	40 – 50%
Organic Matter[u]	21.5%	38.1%	30 – 70% (Dry weight)
Total Nitrogen[t]	1.0%	1.8%	0.5 – 2.5% (Dry weight)
Organic Nitrogen[s]	1.0%	1.8%	n/a
Ammonium N[r]	2.8 mg/kg	5.0 mg/kg	n/a
Carbon[q]	13.8%	24.5%	< 54%
Carbon:Nitrogen Ratio	13.90	13.90	< 20 (Dry weight)
Phosphorus[p]	0.63%	1.11%	n/a
Potassium[o]	0.57%	1.02%	n/a
Sample 8 Analyte	Results (As is basis)	Results (Dry weight basis)	Normal Range
pH[y]	8.0	n/a	5.0 – 8.5
Soluble Salts[x] (1:5 w:w)	1.96 mmhos/cm	n/a	1 – 10 mmhos/cm
Solids[w]	57.5%	n/a	50 – 60%
Moisture[v]	42.5%	n/a	40 – 50%
Organic Matter[u]	21.5%	37.3%	30 – 70% (Dry weight)

Table 2 Cont.

Total Nitrogen[t]	0.8%	1.4%	0.5 – 2.5% (Dry weight)
Organic Nitrogen[s]	0.8%	1.4%	n/a
Ammonium N[r]	6.4 mg/kg	11.1 mg/kg	n/a
Carbon[q]	12.8%	22.2%	< 54%
Carbon:Nitrogen Ratio	16.0	16.0	< 20 (Dry weight)
Phosphorus[p]	0.57%	0.99%	n/a
Potassium[o]	0.61%	1.06%	n/a
Sample 9 Analyte	Results (As is basis)	Results (Dry weight basis)	Normal Range
pH[y]	8.2	n/a	5.0 – 8.5
Soluble Salts[x] (1:5 w:w)	2.28 mmhos/cm	n/a	1 – 10 mmhos/cm
Solids[w]	51.3%	n/a	50 – 60%
Moisture[v]	48.7%	n/a	40 – 50%
Organic Matter[u]	19.4%	37.7%	30 – 70% (Dry weight)
Total Nitrogen[t]	0.8%	1.5%	0.5 – 2.5% (Dry weight)
Organic Nitrogen[s]	0.8%	1.5%	n/a
Ammonium N[r]	2.6 mg/kg	5.0 mg/kg	n/a

Table 2 Cont.

Carbon[q]	12.6%	24.5%	< 54%
Carbon:Nitrogen Ratio	15.90	15.90	< 20 (Dry weight)
Phosphorus[p]	0.37%	0.72%	n/a
Potassium[o]	0.47%	0.91%	n/a
Sample 10 Analyte	Results (As is basis)	Results (Dry weight basis)	Normal Range
pH[y]	7.9	n/a	5.0 – 8.5
Soluble Salts[x] (1:5 w:w)	1.91 mmhos/cm	n/a	1 – 10 mmhos/cm
Solids[w]	56.6%	n/a	50 – 60%
Moisture[v]	43.4%	n/a	40 – 50%
Organic Matter[u]	18.3%	32.3%	30 – 70% (Dry weight)
Total Nitrogen[t]	0.7%	1.3%	0.5 – 2.5% (Dry weight)
Organic Nitrogen[s]	0.7%	1.3%	n/a
Ammonium N[r]	2.8 mg/kg	5.0 mg/kg	n/a
Carbon[q]	10.6%	18.7%	< 54%
Carbon:Nitrogen Ratio	14.40	14.40	< 20 (Dry weight)
Phosphorus[p]	0.27%	0.47%	n/a

Table 2 Cont.

Potassium[o]	0.50%	0.89%	n/a
Sample 11 Analyte	Results (As is basis)	Results (Dry weight basis)	Normal Range
pH[y]	8.1	n/a	5.0 – 8.5
Soluble Salts[x] (1:5 w:w)	1.21 mmhos/cm	n/a	1 – 10 mmhos/cm
Solids[w]	58.8%	n/a	50 – 60%
Moisture[v]	41.2%	n/a	40 – 50%
Organic Matter[u]	25.8%	43.9%	30 – 70% (Dry weight)
Total Nitrogen[t]	0.8%	1.4%	0.5 – 2.5% (Dry weight)
Organic Nitrogen[s]	0.8%	1.4%	n/a
Ammonium N[r]	18.9 mg/kg	32.1 mg/kg	n/a
Carbon[q]	14.3%	24.3%	< 54%
Carbon:Nitrogen Ratio	17.00	17.00	< 20 (Dry weight)
Phosphorus[p]	0.25%	0.43%	n/a
Potassium[o]	0.39%	0.66%	n/a

[z]Compost analysis was conducted at Pennsylvania State University Agricultural Analytical Services Laboratory (University Park, Pennsylvania).

[y]The pH of the finished compost was measured by making a slurry of compost and deionized water and then blended to a ratio of 1:5. The sample was then shaken for 20 minutes at room temperature to allow the salts to solubilize in the deionized water. The pH was then measured with an electrometric pH meter (TMECC 2002). The pH of the finished compost ranged from 7.9 to 8.4, which is slightly alkaline, but still within the typical pH range of compost (5.0-8.5).

[x]The soluble salts were measured by taking the electrical conductivity in a 1:5 (compost:water, weight ratio) slurry and was measured in units of millimhos/cm.

[w]The % solids was measured by weighing a sample and then drying it at 70 (+/- 5) degrees Celsius and then re-weighed. The remaining dry solids fraction represented the total solids, and the evaporated fraction represented the % moisture (TMECC 2002)

[v]The % moisture was measured by weighing a sample and then drying it at 70 (+/- 5) degrees Celsius and then re-weighed. The remaining dry solids fraction represented the total solids, and the evaporated fraction represented the % moisture (TMECC 2002)

[u]The % organic matter of the finished compost was measured by using the Loss-On-Ignition Organic Matter Method; which is a direct determination method that indicates organic matter content by quantifying the amount of solid material combusted relative to the original oven dried sample (TMECC 2002).

[t]The nitrogen content of the finished compost was determined by using the methodologies specified in the Test Methods for the Examination of Composting and Compost (TMECC 2002), specifically the Total Kjeldahl Nitrogen Semi-Micro Kjeldahl technique (TMECC 2002).

[s]The organic nitrogen content of the finished compost was determined by using the methodologies specified in the Test Methods for the Examination of Composting and Compost (TMECC 2002), specifically the Total Kjeldahl Nitrogen Semi-Micro Kjeldahl technique (TMECC 2002).

[r]The ammonium nitrogen content of the finished compost was determined by using the methodologies specified in the Test Methods for the Examination of Composting and Compost (TMECC 2002), specifically the Total Kjeldahl Nitrogen Semi-Micro Kjeldahl technique (TMECC 2002).

[q]The total carbon content of the finished compost in this study was measured by the Combustion with CO_2 Detection method. This method uses a carbon analyzer (Leco CR-12) to determine total organic carbon in compost. The analyzer operates on the principle of total combustion of a sample in an oxygen-rich atmosphere of a 2500 degree Fahrenheit resistance furnace (TMECC 2002). The CO_2 produced by the combustion is swept into an oxygen stream through anhydrone tubes to scrub H_2O vapor from the stream (TMECC 2002). The CO_2 stream is then fed into the infrared detector and the amount of CO_2 produced is measured.

[p]The phosphorus content of the finished compost in this study was measured by digesting an air-dried, milled sample and determining the phosphorus content using inductively coupled plasma emission spectrospy (ICP).

[o]The potassium content of the finished compost in this study was measured by digesting an air-dried, milled sample and determining the potassium content using inductively coupled plasma emission spectrospy (ICP).

The trace elements and heavy metal content of the finished compost in this study were measured by the nitric acid digestion method described in section 4.06 in the Test Methods for the Examination of Composting and Compost (2002). The trace elements and heavy metal (arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, zinc) content of the finished compost (Table 3) in this study were all within the acceptable levels prescribed by the Environmental Protection Agency.

TABLE 3.

Trace elements and heavy metal test results from certified quality testing laboratory[z] in the study of the use of composting as a means to manage the invasive species water hyacinth.

Analyte Sample 1	Results (As is basis)	Results (Dry weight basis)	EPA[y] Limit
Arsenic (As)	7.4 mg/kg	10.1 mg/kg	41 mg/kg
Cadmium (Cd)	0.5 mg/kg	0.7 mg/kg	39 mg/kg
Copper (Cu)	22.2 mg/kg	30.4 mg/kg	1500 mg/kg
Lead (Pb)	8.2 mg/kg	11.1 mg/kg	300 mg/kg
Mercury (Hg)	0.02 mg/kg	0.02 mg/kg	17 mg/kg
Molybdenum (Mo)	1.5 mg/kg	2.1 mg/kg	75 mg/kg
Nickel (Ni)	10.2 mg/kg	13.9 mg/kg	420 mg/kg
Selenium (Se)	1.1 mg/kg	1.5 mg/kg	100 mg/kg
Zinc (Zn)	54.5 mg/kg	74.4 mg/kg	2800 mg/kg
Analyte Sample 2	Results (As is basis)	Results (Dry weight basis)	EPA Limit
Arsenic (As)	6.2 mg/kg	8.9 mg/kg	41 mg/kg
Cadmium (Cd)	0.4 mg/kg	0.5 mg/kg	39 mg/kg
Copper (Cu)	18.0 mg/kg	25.9 mg/kg	1500 mg/kg
Lead (Pb)	6.9 mg/kg	9.9 mg/kg	300 mg/kg
Mercury (Hg)	0.01 mg/kg	0.02 mg/kg	17 mg/kg
Molybdenum (Mo)	1.1 mg/kg	1.6 mg/kg	75 mg/kg
Nickel (Ni)	8.2 mg/kg	11.8 mg/kg	420 mg/kg
Selenium (Se)	1.1 mg/kg	1.6 mg/kg	100 mg/kg

Table 3 Cont.

Zinc (Zn)	47.6 mg/kg	68.3 mg/kg	2800 mg/kg
Analyte Sample 3	Results (As is basis)	Results (Dry weight basis)	EPA Limit
Arsenic (As)	5.5 mg/kg	8.5 mg/kg	41 mg/kg
Cadmium (Cd)	0.3 mg/kg	0.5 mg/kg	39 mg/kg
Copper (Cu)	16.4 mg/kg	25.1 mg/kg	1500 mg/kg
Lead (Pb)	6.3 mg/kg	9.7 mg/kg	300 mg/kg
Mercury (Hg)	0.01 mg/kg	0.02 mg/kg	17 mg/kg
Molybdenum (Mo)	1.0 mg/kg	1.6 mg/kg	75 mg/kg
Nickel (Ni)	7.7 mg/kg	11.8 mg/kg	420 mg/kg
Selenium (Se)	1.0 mg/kg	1.6 mg/kg	100 mg/kg
Zinc (Zn)	44.5 mg/kg	68.4 mg/kg	2800 mg/kg
Analyte Sample 4	Results (As is basis)	Results (Dry weight basis)	EPA Limit
Arsenic (As)	5.8 mg/kg	8.7 mg/kg	41 mg/kg
Cadmium (Cd)	0.4 mg/kg	0.6 mg/kg	39 mg/kg
Copper (Cu)	27.9 mg/kg	41.4 mg/kg	1500 mg/kg
Lead (Pb)	6.1 mg/kg	9.0 mg/kg	300 mg/kg
Mercury (Hg)	0.01 mg/kg	0.01 mg/kg	17 mg/kg
Molybdenum (Mo)	1.1 mg/kg	1.7 mg/kg	75 mg/kg
Nickel (Ni)	7.6 mg/kg	11.3 mg/kg	420 mg/kg
Selenium (Se)	1.1 mg/kg	1.7 mg/kg	100 mg/kg

Table 3 Cont.

Zinc (Zn)	65.7 mg/kg	97.4 mg/kg	2800 mg/kg
Analyte Sample 5	Results (As is basis)	Results (Dry weight basis)	EPA Limit
Arsenic (As)	5.3 mg/kg	8.7 mg/kg	41 mg/kg
Cadmium (Cd)	0.3 mg/kg	0.6 mg/kg	39 mg/kg
Copper (Cu)	33.9 mg/kg	55.0 mg/kg	1500 mg/kg
Lead (Pb)	6.7 mg/kg	10.8 mg/kg	300 mg/kg
Mercury (Hg)	0.01 mg/kg	0.01 mg/kg	17 mg/kg
Molybdenum (Mo)	1.0 mg/kg	1.7 mg/kg	75 mg/kg
Nickel (Ni)	6.9 mg/kg	11.2 mg/kg	420 mg/kg
Selenium (Se)	1.0 mg/kg	1.7 mg/kg	100 mg/kg
Zinc (Zn)	69.5 mg/kg	112.9 mg/kg	2800 mg/kg
Analyte Sample 6	Results (As is basis)	Results (Dry weight basis)	EPA Limit
Arsenic (As)	5.7 mg/kg	8.3 mg/kg	41 mg/kg
Cadmium (Cd)	0.4 mg/kg	0.5 mg/kg	39 mg/kg
Copper (Cu)	35.1 mg/kg	51.0 mg/kg	1500 mg/kg
Lead (Pb)	6.1 mg/kg	8.9 mg/kg	300 mg/kg
Mercury (Hg)	0.01 mg/kg	0.02 mg/kg	17 mg/kg
Molybdenum (Mo)	1.1 mg/kg	1.5 mg/kg	75 mg/kg
Nickel (Ni)	7.3 mg/kg	10.6 mg/kg	420 mg/kg
Selenium (Se)	1.1 mg/kg	1.5 mg/kg	100 mg/kg

Table 3 Cont.

Zinc (Zn)	119.0 mg/kg	172.6 mg/kg	2800 mg/kg
Analyte Sample 7	Results (As is basis)	Results (Dry weight basis)	EPA Limit
Arsenic (As)	4.7 mg/kg	8.4 mg/kg	41 mg/kg
Cadmium (Cd)	0.3 mg/kg	0.6 mg/kg	39 mg/kg
Copper (Cu)	41.6 mg/kg	73.8 mg/kg	1500 mg/kg
Lead (Pb)	3.5 mg/kg	6.1 mg/kg	300 mg/kg
Mercury (Hg)	0.01 mg/kg	0.02 mg/kg	17 mg/kg
Molybdenum (Mo)	1.0 mg/kg	1.8 mg/kg	75 mg/kg
Nickel (Ni)	5.5 mg/kg	9.7 mg/kg	420 mg/kg
Selenium (Se)	1.0 mg/kg	1.8 mg/kg	100 mg/kg
Zinc (Zn)	86.4 mg/kg	153.2 mg/kg	2800 mg/kg
Analyte Sample 8	Results (As is basis)	Results (Dry weight basis)	EPA Limit
Arsenic (As)	4.1 mg/kg	7.1 mg/kg	41 mg/kg
Cadmium (Cd)	0.3 mg/kg	0.5 mg/kg	39 mg/kg
Copper (Cu)	31.3 mg/kg	54.4 mg/kg	1500 mg/kg
Lead (Pb)	4.2 mg/kg	7.2 mg/kg	300 mg/kg
Mercury (Hg)	0.01 mg/kg	0.02 mg/kg	17 mg/kg
Molybdenum (Mo)	0.9 mg/kg	1.6 mg/kg	75 mg/kg
Nickel (Ni)	5.5 mg/kg	9.6 mg/kg	420 mg/kg
Selenium (Se)	0.9 mg/kg	1.6 mg/kg	100 mg/kg

Table 3 Cont.

Zinc (Zn)	67.0 mg/kg	116.5 mg/kg	2800 mg/kg
Analyte Sample 9	Results (As is basis)	Results (Dry weight basis)	EPA Limit
Arsenic (As)	3.0 mg/kg	5.9 mg/kg	41 mg/kg
Cadmium (Cd)	0.3 mg/kg	0.6 mg/kg	39 mg/kg
Copper (Cu)	23.5 mg/kg	45.7 mg/kg	1500 mg/kg
Lead (Pb)	4.4 mg/kg	8.5 mg/kg	300 mg/kg
Mercury (Hg)	0.03 mg/kg	0.05 mg/kg	17 mg/kg
Molybdenum (Mo)	0.9 mg/kg	1.7 mg/kg	75 mg/kg
Nickel (Ni)	4.0 mg/kg	7.9 mg/kg	420 mg/kg
Selenium (Se)	0.9 mg/kg	1.7 mg/kg	100 mg/kg
Zinc (Zn)	48.6 mg/kg	94.7 mg/kg	2800 mg/kg
Analyte Sample 10	Results (As is basis)	Results (Dry weight basis)	EPA Limit
Arsenic (As)	3.7 mg/kg	6.6 mg/kg	41 mg/kg
Cadmium (Cd)	0.3 mg/kg	0.5 mg/kg	39 mg/kg
Copper (Cu)	16.7 mg/kg	29.5 mg/kg	1500 mg/kg
Lead (Pb)	5.5 mg/kg	9.6 mg/kg	300 mg/kg
Mercury (Hg)	0.01 mg/kg	0.02 mg/kg	17 mg/kg
Molybdenum (Mo)	0.9 mg/kg	1.6 mg/kg	75 mg/kg
Nickel (Ni)	5.3 mg/kg	9.3 mg/kg	420 mg/kg
Selenium (Se)	0.9 mg/kg	1.6 mg/kg	100 mg/kg

Table 3 Cont.

Zinc (Zn)	43.3 mg/kg	76.4 mg/kg	2800 mg/kg
Analyte Sample 11	Results (As is basis)	Results (Dry weight basis)	EPA Limit
Arsenic (As)	3.2 mg/kg	5.4 mg/kg	41 mg/kg
Cadmium (Cd)	0.5 mg/kg	0.9 mg/kg	39 mg/kg
Copper (Cu)	12.7 mg/kg	21.5 mg/kg	1500 mg/kg
Lead (Pb)	5.2 mg/kg	8.8 mg/kg	300 mg/kg
Mercury (Hg)	0.02 mg/kg	0.03 mg/kg	17 mg/kg
Molybdenum (Mo)	2.8 mg/kg	4.8 mg/kg	75 mg/kg
Nickel (Ni)	5.2 mg/kg	8.8 mg/kg	420 mg/kg
Selenium (Se)	1.5 mg/kg	2.6 mg/kg	100 mg/kg
Zinc (Zn)	31.9 mg/kg	54.3 mg/kg	2800 mg/kg

[z]Compost analysis was conducted at Pennsylvania State University Agricultural Analytical Services Laboratory (University Park, Pennsylvania).

[y]EPA limits retrieved from Stofella *et al*. 2001.

Therefore, most samples of compost created from water hyacinth were in the acceptable to ideal ranges given industry quality standards. It was noted that samples that showed unacceptable ranges of some variables were most likely due to inexperienced equipment operators at the beginning of the study which resulted in clay and other materials being inadvertently mixed in with the compost (Rynk *et al.* 1992). These problems were corrected in newer piles as equipment operators gained experience.

Additionally, improvements to the site with cleaner surfaces such as rock added to work area could help with new piles in the future as the project grows.

Findings Related to Objective Six

The sixth objective of this study was to determine how and if the removal of water hyacinth impacts water quality. The benefits of removing water hyacinth in one study found that the oxygen depleting load per hectare of water hyacinth equaled the sewage created by 80 individuals (Raynes 1964; Gopal 1987). Subsequently, it has been found that the amount of nitrogen and phosphorus removed per hectare of water hyacinth is equivalent to the sewage created by 500 people (Boyd 1970). A total of 22,000 pounds of water hyacinth was collected during the months of August through November, 2009. Estimates of hyacinth removed was determined by weighing 44 gallon bins filled with water hyacinth and creating an average based on the number of bins filled during harvests in total.

TABLE 4.
Water hyacinth collection dates and pounds of water hyacinth collected in the study of the use of composting as a means to manage the invasive species water hyacinth

Water hyacinth collection date	Pounds collected[z]
August 21st, 2009	4000
August 25th, 2009	2000
September 8th, 2009	2000
September 17th, 2009	4000
September 26th, 2009	4000
November 3rd, 2009	4000
November 17th, 2009	2000

[z]Water hyacinth totals were estimated by weighing 44 gallon bins filled with water hyacinth and creating an average based on the number of bins collected during the study period in total.

Based on the water hyacinth collection dates, water quality data were requested from the Texas Stream Team for corresponding collection sites and dates. The Texas Stream Team is a group of volunteers that are trained to gather information about the natural resources of Texas (RSI 2010). Water quality variables that were considered included electrical conductivity and dissolved oxygen content. Electrical conductivity was considered due to the known nutrient uptake of water hyacinth (Gopal 1987). Dissolved oxygen was measured because water hyacinth is known to deplete the oxygen content of water bodies (Gopal 1987). However, data points were limited to those data collection points gathered by volunteers which did not include any of those (August-December) months in 2009. Therefore, the next 2 months that data were available (February through March, 2010) were used for comparison to the 2008 data.

Frequencies and paired t-tests were used to statistically analyze water quality data (Table 5). There were no statistically significant differences between the water quality samples taken prior to collection versus those taken after water hyacinth collection dates (Table 5). The mean for the electrical conductivity level of the water before collection (August through December 2008) was 666.00 and the mean after water hyacinth collection (February through March 2010) was 548.00. The mean for the dissolved oxygen content of the water before collection (August through December 2008) was 8.28 and the mean after water hyacinth collection (February through March 2010) was 10.14. Therefore, while 22,000 pounds of water hyacinth was removed from the water body and that quantity does have filtration potential, water hyacinth removal did not appear to be detrimental to water quality. However, removing water hyacinth is known to improve

water quality as the oxygen depleting load per hectare of water hyacinth has been found to equal the sewage created by 80 individuals (Raynes 1964; Gopal 1987).

TABLE 5.
Results of paired t-test statistical analyses of water quality data in the study of the use of composting as a means to manage the invasive species water hyacinth.

Category	Mean	N	SD[z]	t	df	*P*
Pair 1 EC[y] 2008	666.00	5	20.73644	0.833	4	0.452
Pair 1 EC[y] 2009	548.00	5	308.33423			
Pair 2 DO[x] 2008	8.2800	5	2.06083	-1.375	4	0.241
Pair 2 DO[x] 2009	10.1400	5	1.89552			

[z]Standard deviation

[y]Electrical conductivity

[x]Dissolved oxygen

CHAPTER V

SUMMARY & CONCLUSIONS

The main objective of this study was to determine if large scale composting is an effective means of managing water hyacinth by rendering the seeds and other propagules non-viable while producing a quality compost product for the horticultural industry.

The specific objectives of this study were to:

1) Germinate seeds of water hyacinth by implementing germination tests that have shown success in related studies (Gopal 1987).

2) Determine the temperatures at which water hyacinth seeds are rendered non-viable.

3) Develop a large-scale composting system at the Texas State Muller Farm that uses water hyacinth harvested from Spring Lake and nearby areas of the San Marcos River as a feedstock.

4) Determine if the composting process renders water hyacinth seeds and propagules non-viable.

5) Determine the quality of the compost produced.

6) Determine how and if the removal of water hyacinth impacts water quality.

Objective 1

The first objective of this study was to germinate seeds of water hyacinth by implementing germination tests that have shown success in related studies (Gopal 1987). Previous research has been inconclusive on the ideal conditions for water hyacinth seed

germination, but it was found in this study that 62% (62/100) of water hyacinth seeds successfully germinated on filter paper media soaked in distilled water and placed in petri dishes held at a constant temperature of 80 degrees Fahrenheit for 14 days. It was also found that scarification is not required for successful germination of water hyacinth seeds given that seeds of both conditions (scarified, unscarified) germinated. The successful germination of water hyacinth seeds enabled researchers to continue the study on determining if the composting process kills seeds and incorporate the use of germination tests if/when necessary.

Objective 2

The second objective of this study was to determine the temperatures at which water hyacinth seeds were rendered non-viable. This study found that water hyacinth seeds were rendered non-viable at temperatures at or above 135 degrees Fahrenheit. This finding allows for water hyacinth to be safely utilized as a feedstock in the composting process even though it is an invasive species since temperatures above 135 degrees Fahrenheit kills seeds and these temperatures are relatively easy to maintain in a compost pile when appropriate proportions of carbon and nitrogen-containing feedstocks are used (Rynk *et al.* 1992). This method for determining the temperatures at which seeds and propagules are rendered non-viable could be replicated with other invasive plant species to determine if they have the potential to be utilized as feedstocks in the composting process as well. There is also the potential to make money from composting invasive weeds while helping manage populations of invasive species in the environment.

Objective 3

The third objective of this study was to develop a large-scale composting system at the Texas State Muller Farm that used water hyacinth harvested from Spring Lake and nearby areas of the San Marcos River as a feedstock. Eleven compost piles were created from 22,000 pounds of water hyacinth, 20,000 pounds of food waste, 25,000 pounds of poultry litter, and 38,000 pounds of wood chips. In the past, water hyacinth in this area of Spring Lake was typically harvested and dried on the river bank where it was a wasted product and also had the potential to add to the seed bank around Spring Lake. Poultry litter is considered to be a groundwater contaminating agent and the expense to dispose of the litter costs a substantial amount of money. Food waste from the Texas State cafeterias was previously headed to the dumpster and cost the university in trash hauling fees. This study created an estimated 66 yards of compost valued at $1980 from materials that were otherwise considered problematic (Greg Frank, personal communication 2010). This process could be replicated at other universities around the world that have access to invasive species and adequate space for a composting operation. Additionally, the estimated savings from not having to use other management techniques makes composting an appealing waste management alternative.

Objective 4

The fourth objective of this study was to determine if the composting process renders water hyacinth seeds and propagules non-viable. One hundred 1 gallon samples were collected in this study and then screened to 2mm to observe for seeds and other propagules. No seeds or propagules of water hyacinth were found. This allows for the

species to be composted without the potential danger of it spreading. Creating a composting system to kill invasive seeds has the potential to benefit several states in the United States as well as many countries around the world that are plagued by invasive species. The states in the U.S. where water hyacinth is listed as an invasive species includes California, Texas, Louisiana, Georgia and Florida. All of these states are major horticultural crop producers (Stoffella and Kahn 2001). Currently governments around the world are spending a substantial amount of money to control invasive plant species with no return. By composting invasive plant species, countries can manage the species while turning them into a valuable product. Since many of the countries that have problems with invasive plant species also have poor soil, the addition of compost could help restore lost organic matter leading to more agricultural productivity. Developing countries with invasive plant species problems could manage a large-scale composting system with basic agricultural equipment and a small investment (Rynk *et al.* 1992).

Objective 5

The fifth objective of this study was to determine the quality of the compost produced. This study found that the quality of compost created from water hyacinth was in the acceptable to ideal ranges of given industry quality standards. The piles that fell out of the acceptable to ideal ranges were attributed to inexperienced equipment operators at the beginning of the study and were corrected in newer piles. Therefore, with experienced operators and improvements to the compost pad surface, compost of a more consistent and high quality can be produced by those replicating the study. The quality of the compost produced is adequate for any type of application making it highly desirable to horticulturists and other frequent users of compost. However, it should be noted that

water hyacinth absorbs water contaminants so compost produced will continually need to be quality tested.

Objective 6

The sixth objective of this study was to determine how and if the removal of water hyacinth impacts water quality. Pre-test and post-test water quality samples were collected for electrical conductivity and dissolved oxygen content at the water hyacinth harvesting site. This study did not indicate that the removal of water hyacinth impacted the water quality of the area either negatively or positively. Water quality sample data was collected by volunteers from the Texas Stream and limited; therefore, results may be distorted from a lack of data points. Other possible explanations for the results could include that the area where water hyacinth was collected was routinely harvested by volunteers before the study had occurred and therefore, no changes were observed. Although this study harvested a higher volume of water hyacinth when compared to the quantities collected by volunteers in the past, it was still a small-scale pilot where water hyacinth was only manually harvested and volumes were limited. However, if a larger volume is harvested in the future, harvested qualities may impact water quality. Therefore, care should be taken not to harvest the water hyacinth to the point where it negatively impacts water quality.

Recommendations for future research:

1) Research involving the composting potential of other invasive aquatic species should be investigated.

2) Research should be conducted involving other water bodies in Texas, specifically Caddo Lake where other composting techniques could investigate the potential of composting to sequester heavy metals known to accumulate in water hyacinth.
3) Future research should be conducted studying the economics of compost management of invasive species such as water hyacinth versus other management techniques such as biological and chemical control methods.
4) Research should be conducted that investigates the use and application of water hyacinth compost for various horticultural purposes.
5) Future research should be conducted with more extensive data that investigates how and if the removal of water hyacinth impacts water quality.

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VITA

John Edward Montoya, Jr. was born in Tucson, Arizona, on June 11, 1980, the son of Elaine Ann Montoya and John Edward Montoya. After completing his work at Brussels American School, Belgium, in 1998, he entered Texas State University-San Marcos. He received the degree Bachelor of Science from Texas State in August 2008. In September of 2008, he entered the Graduate College of Texas State.

Permanent Address: PO Box 30964

Honolulu, HI 96820

This thesis was typed by John E. Montoya.